Schwing, F.B., D.M. Palacios, and S.J. Bograd. 2005. El Niño impacts on the California Current ecosystems.
U.S. CLIVAR Newsletter, Vol. 3, No. 2, 5-8.
(unpublished manuscript).

El Niño Impacts on the California Current Ecosystem

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1. Introduction

With the recognition that marine populations respond to climate variability, and that climate events such as El Niño (EN) impact the production and distribution of fish stocks in a complex interaction with fishing pressure, NOAA Fisheries scientists and their colleagues have made research in understanding these links a priority. An important facet of EN prediction is the improved ability to anticipate its social and economic consequences, including impacts on fisheries and marine ecosystem productivity.

It was initially believed that EN was principally a tropical phenomenon, and that its ecosystem impacts were limited to near-equatorial waters off western South America. After the 1957-58 EN, scientists began to link a number of major shifts in marine populations in the California Current regional marine ecosystem (CC) to this event (Sette and Isaacs 1960). This was possibly the first time that EN was recognized as a global phenomenon with widespread ecological consequences. At this same time, scientists realized that past EN events had also disrupted the CC ecosystem.

2. The Physical Response of the California Current to El Niño

The physical response of the North Pacific and the CC to EN has been widely documented (Chelton et al. 1982; Emery and Hamilton 1985; Wooster and Fluharty 1985; Mysak 1986; Chavez et al., 2002 and papers therein). From an ecosystem perspective, the primary physical factors of importance are those affecting general biological productivity and availability of food, aggregation for schooling and reproduction, larval dispersal, barriers to migration, physiological effects of extreme conditions, and changes in species composition and interactions.

Figure 1 illustrates how some of these factors have changed during the major EN events of the past half-century. The upper water column warms by 2-3°C during most ENs. The thermocline, an indication of vertical stratification, strengthens and deepens. These are reflections of weaker coastal upwelling, less wind mixing, and a compensating adjustment in alongshelf transport that results in less southward flow, which leads to further warming. Coastal Kelvin waves that may be connected to equatorial Kelvin waves will also contribute to a depressed thermocline during some events.

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These changes in water column structure are not the same for each EN event, nor are the ambient conditions the same at the time of each event. There has been a significant trend since 1950 towards enhanced stratification and a deeper thermocline along the California coast (Figure 1; Palacios et al. 2004), as part of a long-term warming trend and subsequent reduction in biological productivity of the CC (Roemmich and McGowan 1995). EN events are impacting the CC against this backdrop of low-frequency climate variability.

3. The Ecosystem Response

Since coastal upwelling is a dominant physical process in the CC and one that is responsible for the system's high biological production, EN influences such as reduced upwelling-favorable winds and stronger vertical stratification will reduce nutrient input to surface waters and lower plankton biomass (Kahru and Mitchell 2000; Bograd and Lynn 2001), and alter production and distribution of many important fish stocks and marine mammals (Sette and Isaacs 1960; Wooster and Fluharty 1985; Chavez et al. 2002; and papers therein).

EN typically means warmer water, which accelerates growth in some species, such as California sardine, but lowers the reproductive capability of rockfish, squid and other species that prefer cooler temperatures. Marine mammal and bird populations are also stressed by warm conditions and reduced food availability, leading to reduced reproduction, starvation and mass mortality of young. EN conditions also create a northward and onshore extension of the range of many populations, including tropical species such as giant squid, barracuda and tunas uncommon to the northern portion of the CC. Highly migratory trans-Pacific pelagic fish, including albacore and other tuna varieties, extend their range and concentrate near the coast, where they prey upon nearshore species, but become easier prey themselves for fishers.

In most EN events, the southward surface transport of the CC is reduced, in part because of geostrophic adjustments to higher coastal sea level. Northward flow of the deeper California Undercurrent over the continental slope is increased, which

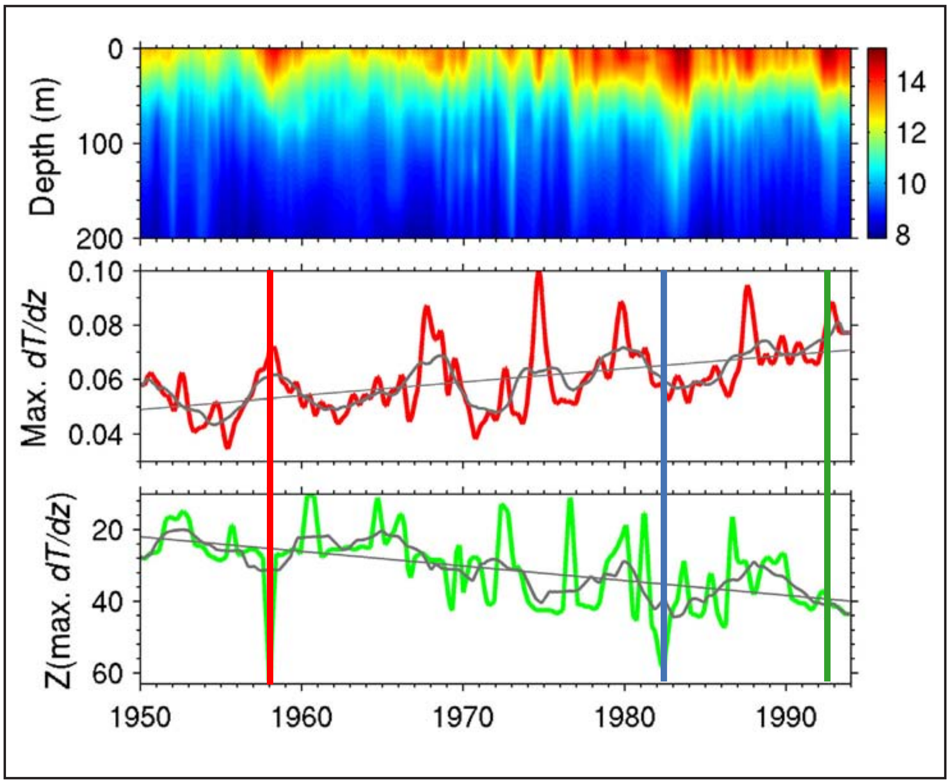

Figure 1: (top) Monthly time series of 0-200 m temperatures from a 1° box centered at 36.5°N, 123.5°W in the California Current. Monthly time series of (b) maximum dT/dz (°C m^{-1}) and depth of the maximum dT/dz (m) derived from the temperature series. The temperatures in (top) are the modeled trend component from a state-space decomposition of observed temperatures from the World Ocean Database (Palacios et al., 2004). Colored curves (bottom) are the monthly series, dark gray curves are the 37-point running averages, and thin gray lines are the regression of each variable on year. Vertical lines mark the approximate times that the El Niño events of 1957-58, 1982-83 and 1991-92 impacted the California Current.

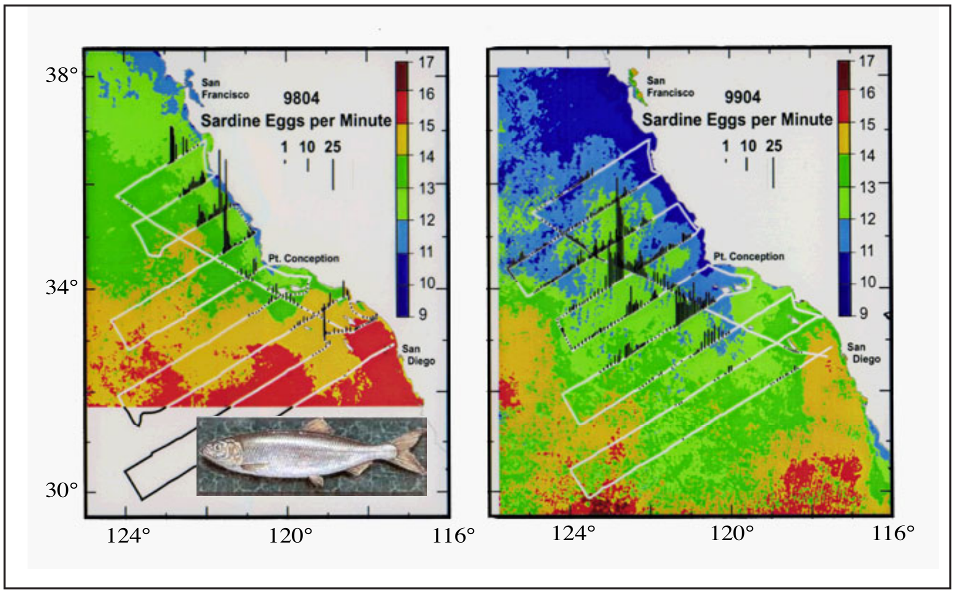

Figure 2: Stick plots of California sardine egg counts per minute from the Continuous Underway Fish Egg Sampler (CUFES) deployed on the (a) April 1998 (El Niño conditions) and (b) April 1999 (La Niña conditions) CalCOFI cruises off southern California, overlaid on satellite-derived sea surface temperature. Adult sardine shown in inset. Courtesy of Ron Lynn and the NOAA Southwest Fisheries Science Center.

may lead to the introduction of unusual warm-water planktonic species to the CC region. These include warm-water krill, pelagic red crab, sedentary bottom-dwelling fishes, and many fish larval and juvenile stages. This anomalous along-shelf advection is a very different process than the warming of surface waters. Because these two processes may not occur in the same EN, the populations they affect will be more influenced during some events than others.

EN effects can be conflicting. For example, the sardine spawning habitat, which is generally defined as the region

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where SST > 14°C, increased during the 1997-98 EN (Figure 2). However, unusually weak coastal upwelling, indicated by the reduced area of cool SST, led to less food for adults and poor egg production. Record upwelling in 1999 contributed to elevated sardine egg production, despite the more offshore displacement of warmer water. Because of this correspondence between ocean temperature and production, the annual fishery quota of the California sardine is set in part upon recent SSTs. Improving our understanding about climate variability and its biological impacts will allow more examples like the sardine to be incorporated into resource management.

4. Variability between Individual El Niño Events

The CC has a well-documented history of large biotic fluctuations during EN events. However, individual EN events appear to impact specific populations or ecosystem components differently. Recent analysis of the spatial and temporal variability of temperature has identified three dominant types of EN signals in the CC.

The temperature time series in Figure 3, representing the meridional, offshore, and vertical extent of the CC for 1950-93, demonstrate that EN signals extend throughout the CC. They also reflect some of the distinctions between individual El Niño events. These series illustrate the findings of a systematic analysis of upper ocean temperature variability (Mendelssohn et al. 2003) that identified three characteristic patterns of El Niño influence. El Niño events cluster into three distinct patterns with the strongest warm anomalies occurring in the shallow/equatorward, shallow/poleward, and deep/equatorward regions of the CC. Each type is represented by one of the three strongest tropical EN events over this period; 1957–58, 1991–92, and 1982–83, respectively. So, while the 1982-83 EN thermal signal was strongest in the upper thermocline and southern portion of the CCS, the 1991-92 signal was accentuated in surface waters over a broader geographical range. Individual La Niña signals are less spatially variable in the CCS.

These distinct EN types are also likely to have different biological impacts. Specifically, since populations separate spatially with ecosystems (e.g., vertically, meridionally, thermally) as well as temporally (e.g., timing of migration and reproduction), organisms in those regions and times most strongly influenced by a particular EN may also be most impacted. If a consistent relationship between the physical state of a particular EN and its ecological response can be found, then we will be able to project which populations are more likely to be affected by future ENs, thus improving our understanding of climate-ecosystem linkages and the management of living marine resources.

While a comprehensive analysis of the ecosystem response to different EN events is not complete, reports from past major ENs provides evidence that the different spatial physical patterns identified by Mendelssohn et al. (2003) have corresponding regionally distinct biological responses. The primary ecological impact of the 1982-83 EN, which was dominated by a strong thermocline signal and anomalous northward advection, was the northward displacement of coastal bottom-dwelling fishes. In contrast, the 1957-58 and 1997-98 events, which initially featured a broad upper ocean warming, were characterized by a major influx of strong swimming warm-water fish into the CC.

Finally, we must recognize that EN events occur upon longer-term climate

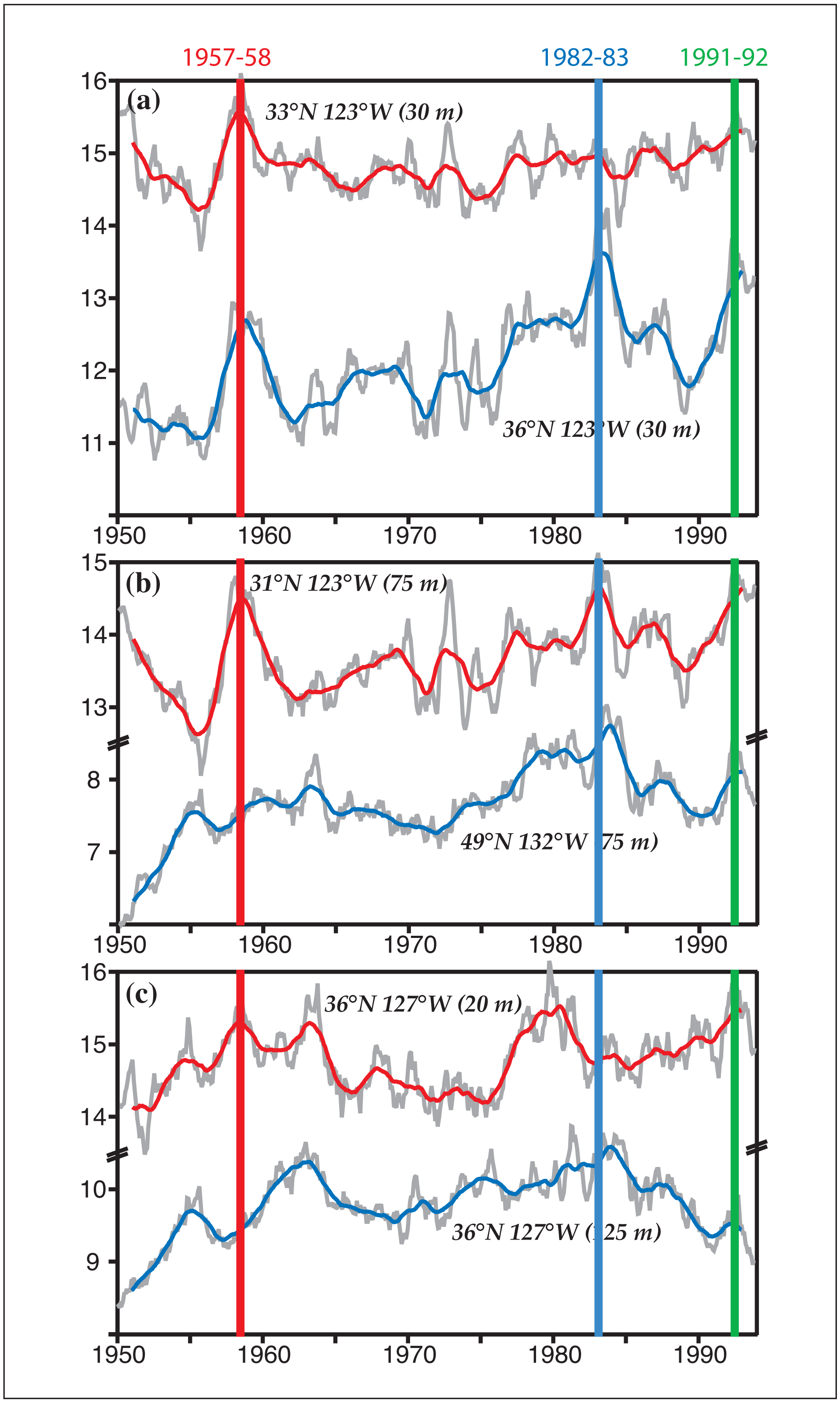

Figure 3: Representative long-term temperature trends from the California Current region derived from a state-space decomposition of observed temperatures from the World Ocean Database (Mendelssohn et al., 2003). These series illustrate the dominant spatial patterns from a common trend analysis of upper-ocean temperatures throughout the California Current: (a) the cross-shore pattern (36°N, 123°W and 33°N, 123°W at 30 m), (b) the alongshore pattern (31°N, 123°W and 49°W, 132°W at 75 m), and (c) the depth pattern (36°N, 127°W at 20 m and 125 m). Light gray curves are the monthly series, and colored curves are the trewess smoother. Vertical lines mark the approximate times that the 1957-58, 1982-83 and 1991-92 El Niño events impacted the California Current.

variability. Multi-decadal regime shifts in the North Pacific (Mantua et al. 1997) lead to extended periods of relatively stronger or weaker ENs, depending upon whether these events develop out of a background warm or cool north Pacific regime. The general warming trend of the past century has also resulted in an implied greater overall impact of recent EN events (Mendelssohn et al. 2005). Understanding the interactions between El Niño cycles and other climate variability, and predicting their combined future impact on marine ecosystems and fishery populations, would be an important activity for CLIVAR to consider. ■

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CLIMODE: a mode water dynamics experiment in support of CLIVAR

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1 Introduction

CLIMODE (CLIvar MOde Water Dynamic Experiment) is focused on a region of huge ocean to atmosphere annual-mean heat loss (>200 W m^{-2}) which occurs over the separated Gulf Stream in the North Atlantic. The region of most intense wintertime ocean heat loss corresponds to an area with relatively warm surface waters that are carried there by the Gulf Stream, Fig.1. Late winter SST's fall to approximately 18˚C as water parcels move east under this cooling. The associated buoyancy loss from the ocean is believed to trigger ocean convection on the northern rim of the subtropical gyre to form what is known as Eighteen Degree Water (EDW) – Worthington (1959; 1976) – the North Atlantic Subtropical Mode Water. The wedge of weakly stratified water spanning temperatures between about 17˚C and 19˚C characteristic of mode water are clearly evident in the Gulf Stream section shown in Fig.2.

The region of EDW formation is particularly relevant to wider CLIVAR goals because, first, the annual mean ocean to atmosphere heat flux over the EDW formation region might be crucial for the maintenance of the Atlantic Storm track (Hoskins and Valdes, 1990). Second, EDW and the associated Gulf Stream recirculation and thermal structure is a key region where oceanic timescales can possibly imprint themselves on the atmosphere. Seasonal to interannual timescales are introduced by the thermal inertia of the ocean mixed layer/EDW layer system, whose evolution through the annual cycle is strongly connected to the re-emergence of SST anomalies from winter to winter (Alexander and Deser, 1995; de Coëtlogon and Frankignoul, 2003). On longer timescales the intensity and path of the Gulf Stream affects air-sea exchange and mode water formation through interannual variations in low-frequency flow as well as lateral eddy heat fluxes – Marshall et al (2001), Czaja and Marshall (2001), Dong and Kelly (2004). How exactly such oceanic influences on climate work is a subject of great importance, controversy and subtlety. Finally, CLIMODE should also be seen as making an important contribution to tying down the basin scale air-sea heat budget and, by implication, quantifying the meridional transport of heat in the Atlantic basin.

CLIMODE is motivated by the fact that there is presently a major disconnect between the best available estimates of EDW formation rates based on air-sea fluxes and what we (think we) know about likely dissipation rates. Either our air-sea flux estimates are grossly in error and/or there is 'missing physics' involved in the basic mechanism of mode water formation, which is not represented in our models. CLIMODE is designed to get to the bottom of this conundrum. A prime candidate for the missing physics is lateral, diabatic exchange through the mixed layer by